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THE POWER OF DECENTRALIZED POWER: WHAT WE CAN LEARN FROM SUCCESSFUL RENEWABLE ENERGY MODELS

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Though Ancient Romans did not install metal sheets on the top of their homes or understand that rays of sunshine could become electric currents, they relied on the sun to fuel the luxury located at the center of the Ancient Romans' social customs: bath houses.[9] They accomplished this with the invention of hypocausts, which are primitive but effective contraptions that trapped hot air in underground cells to heat the baths above. They also harnessed the sun's power more directly by building bath houses with large windows, which allowed the bathwater to absorb the influx of natural heat.[9] Once used in Ancient Rome to power a luxury, radiation heating and hypocausts equate in modern day society to solar panels, a stepping stone towards a more environmentally sustainable future. Though our priorities have become paradoxical with those of civilizations past, the potential of the sun remains timeless, as do Ancient Roman bathhouses as a prime example of small-scale, localized renewable energy systems. From their reliance on a boundlessly outpouring source of unending light to the local scale on which it was captured and channeled, it could be that the principles at the core of Ancient Romans' energy model stand the test of time.

Figure 1: Large windows strategically implemented in the construction of the Baths of Trajan (build AD 104), an ancient Roman bathing complex. *The direction and vastness of these windows allowed for optimal solar heating of the Baths.*

FEATURES

Figure 2: Power grids function as complex systems, spanning miles and dominating countries.

In vast contrast to the standard of Ancient Rome, a fossil-fuel dominated power grid is the energy model governing the U.S. as well as many other countries. Complex and tedious, the methodology of this system can be explained by complexity science or complexity network theory.[1] A "network" is the simplified manifestation of complex network theory.[1] These graphs and representations portraying mathematical concepts such as probability distribution have made it possible to generalize the patterns of complexity enough to comprehend them. "Dynamics" deals with the processes and ramifications of redistributing energy flows within power grids. If there is a blackout, how will energy be reallocated to problem-solve under pressure? The answer is often "not well."

Evolution and self-regulation are also defining traits of complex systems. Here, however, is where the intersections of this model and the deliberate construction defining engineering get interesting. Each component of the power grid is fixed, preventing it from adapting to discrepancies and flaws in singular components of the system at large.[1] The lifeblood of our comfort and survival is a system functioning as an environment—but without the biotic and evolutionary forces that drive its success in the natural world. We wield the power of an orchestra of millions of unsynchronized yet calculated moving pieces. As with an ecosystem, a social dynamic, and the universe at large, the power grid causes us to take for granted a system of paradoxically improbable success and inevitable imperfection.

Humans gut the Earth of its resources in order to maintain an efficient and large-scale system of production and consumerism. Despite all of the innovation every year brings, we are archaic where the source of much of our energy is concerned: As of November 2022, 61% of electricity generated in the U.S. comes from fossil fuels such as natural gas, coal, and petroleum.[2] Though the power grid has become an entity so complex that it mimics the hypersensitive interconnectedness of an ecosystem, we use this advancement not to streamline energy from renewable sources, but to make the use of fossil fuels more widespread and easy. During the industrial revolution, humanity turned to the financially obvious options rather than the cosmically, biologically, and evolutionarily obvious.

Some of the most cost-efficient and widely used methods of energy that fit the latter category include solar power, hydropower, and geothermal power. The sun is the energy source that is and has always been the foundation of living organisms, from a cellular level to the Goldilocks conditions that make human survival possible. Similarly, we are made of water. Likewise, without the heat that we generate to stay alive and that emanates from our bodies, we would be dying off, unsustained. In terms of the source of our energy, why shouldn't we keep ourselves alive with what already keeps us alive—that which is already inherent to living organisms' existence?

The status of the U.S.'s renewable energy progress is not unanimous—many countries have successfully switched to models of almost or entirely renewable energy. Iceland began their switch with "scattered independent power systems around the country".[5] Farmers, inspired by the techniques used to drill oil, innovated personal geothermal and hydropower systems in order to sustain their individual homes. Geothermal energy plants employ the steam from natural sources of hot water to induce the spinning of a turbine, which in turn drives a generator.[3] "Microhydro" and hydropower plants use the kinetic energy of moving water to similarly induce the turning of a turbine and charging of a generator.[7]

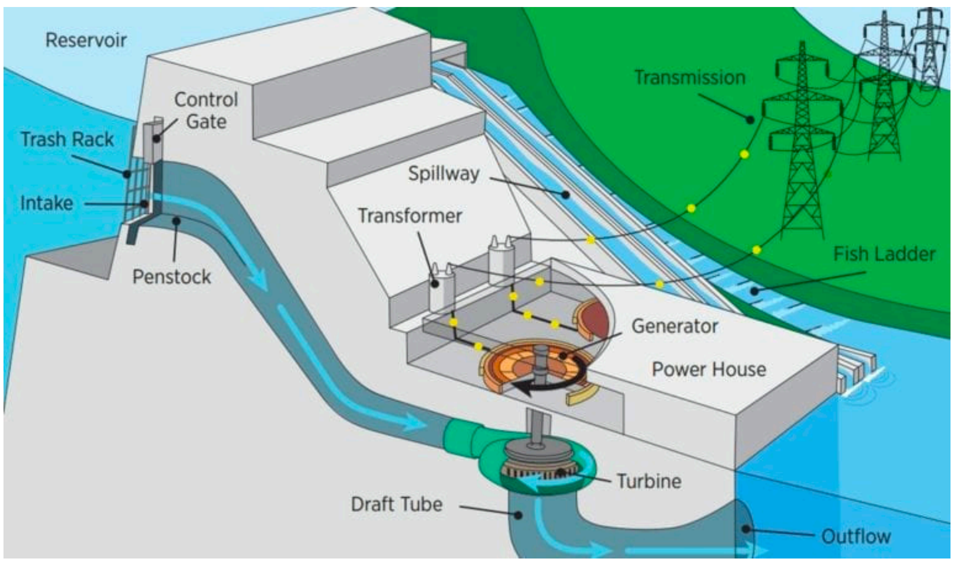

Figure 3: Microhydropower systems take advantage of natural energy produced by running water. *Both hydropower plants and geothermal energy plants employ the use of turbines and generators to generate and store energy.*

Figure 4: Hellisheidi Geothermal Power Plant, the largest geothermal power plant in Iceland, is an example of large-scale renewable energy production.

These systems became commercialized, and now Iceland has successfully transitioned to a country with almost all of their energy coming from renewables.[5]

Nicaragua uses large-scale energy, but also addresses the needs of more rural areas by providing them with decentralized energy sources.[6] According to a study on the politics and methods of Nicaragua's implementation of renewable energy, "Small-scale renewable energy technology is key to […] Decentralized access. This provides independence and autonomy associated with controlling the production of this energy".[6]

According to a report, efforts made in places like Nicaragua, Iceland, and African countries have led to a significant decrease in the percentage of the population living without electricity.[8] The same report states that the number of people relying on renewable energy from decentralized, local sources went from 5 million to 11 million between 2010 and 2019. However, as of 2019, 759 million people still lack access to power.[8] Localized power sources have potential both as a catalyst for wide-scale renewable energy and as a solution for communities in rural, obscure geographic locations without access to power from power grids.

The technology of solar panels is made possible by the photovoltaic effect. Photovoltaic cells are used to convert sunlight to electricity, with the help of copper and its high conductivity.[4] Copper is a renewable resource in a less obvious sense than constantly outpouring counterparts such as the sun and water. Its abundance in nature continues to decrease as we extract and consume it. However, copper is a long way from gone, and it can be reused over and over without losing the qualities that make it valuable for renewable energy technology. Moving forward, as we increase the use of solar panels, copper's renewability factor can be increased by intentionally prolonging its lifespan through reuse. According to a recent study, the use of specific copper compounds for the conversion of the sun's rays to energy can also improve the degree to which solar panels are sustainable to continuously produce.[10]

Solar panels generate energy via redox reactions that transform solar photons to either chemical energy or electrical power. There are two types of metallic semiconductors which can perform this task: p-type and n-type. As wide bandgap materials, n-type semiconductors are most commonly used and can only absorb sunlight in the UV range. When exposed to radiation, oxidate water to conduct electricity. While P-type semiconductors absorb solar photons at a greater variation of wavelengths, they often pay the price of a lower charge carrier mobility. As such, these semiconductors possess a lower speed at which the electric field can cause an electron to flow through it—and, likewise, the speed at which said electric field can pull electrons through itself.

"Stability against degradation" and efficiency are both factors that influence the degree to which copper is reusable and environmentally friendly. According to the study on copper mentioned prior, a specific subcategory of p-type conductors using copper I-based oxides is a more sustainable and efficient alternative to the usual copper types used to construct photovoltaic systems. The elements incorporated in copper I-based oxides are "abundant and nontoxic." If copper I-based oxides are used to construct solar panels more than the common but less economically and conservationally efficient ones that are common now, then the use of solar panels, on both a localized and centralized scale, can become a sustainable, long-term method of renewable energy.

Across the world, an equitable, sustainable, and environmentally friendly forging into the future is imminent yet illusive. Does the answer lie in solar energy,

Figure 5: The San Jacinto Tizate Geothermal Power Plant is one of Nicaragua's main centralized renewable energy sources. *It operates at a relatively low capacity of 72 megawatts; centralized geothermal energy occupies much less of the renewable energy sector than in Iceland.*

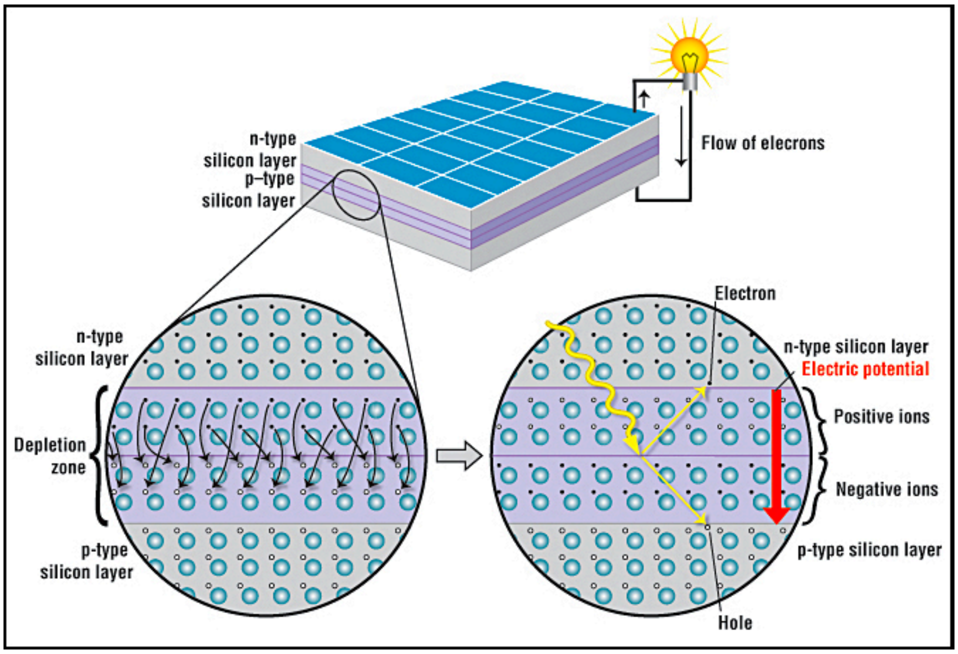

Figure 6: p and n-type semiconductors are often used simultaneously.

or does the environmental price to pay for copper outweigh its potential for energy efficiency? The power grid system, though flawed, supports wide-spread renewable energy systems such as Iceland's, and has the potential to do the same, if developed to be more wide-reaching, or with the supplementation of localized renewable power plants. Whether to address the immediate needs of communities that are off the grid, or in hopes of a slow domino effect where renewable energy sources overtake the fossil fuel-dominated energy sector, small-scale renewable energy sources have shown throughout history that they have no small impact.

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